Coffee Crop Germplasm Vulnerability Statement
Approved by the CCCGC on November 18, 2020

Executive Summary

In fiscal year 2019, the Congress of the United States appropriated an increase in recurrent, base funding to the United States Department of Agriculture (USDA), Agricultural Research Service (ARS), for the purpose of establishing and maintaining a coffee genetic resource collection within the USDA/ARS National Plant Germplasm System. In order to provide technical input on germplasm collection, maintenance, characterization, evaluation, enhancement and effective utilization to the curators of the coffee collections, the Coffee and Cacao Crop Germplasm Committee (CCCGC) was formed in 2019.

Coffee is one of the most important tropical agricultural commodities contributing to the economy of many coffee-producing countries. Coffee cultivation is facing many challenges, one of the most important being climate change and associated impacts such as higher incidence of insect pests and plant pathogens, leading to lower productivity. In the United States, coffee is produced in Hawai'i, Puerto Rico and to a limited extent in California. Even though demand for coffee is rising, Hawai'i has seen a decline in yield. The 2017-18 season reported a decline of 15% overall production to 24.3 million pounds of cherry coffee in the state despite an increase in acreage cultivated. This lower productivity has been attributed to climate change impacts such as reduced rainfall and incidence of pests such as the coffee berry borer and root-knot nematode.

Due to the fact that coffee seeds do not tolerate freezing or drying, the main method of conserving coffee *ex situ* is in field genebanks, which is resource-intensive. Genetic erosion *in situ* is also of concern with almost 60% of *Coffea* species facing some form of threat in the wild with poor representation in *ex situ* collections. Cultivation of coffee has relied on a very narrow genetic base, combined with few breeding efforts that more effectively combine existing genetic diversity, which has made the crop vulnerable to pests and diseases and the impacts of climate change. Early breeding programs concentrated on developing varieties with resistance to pests and diseases, higher yield, or uniform ripening for mechanization, with less emphasis on coffee quality. With the rise of the specialty coffee industry, consumers have become more discerning of taste and flavor. Hence, demand-led breeding needs to be defined and implemented across breeding programs, to make the crop resilient to biotic and abiotic threats and other production traits prioritized by growers and traders, while also improving or maintaining quality.

In order to achieve a sustainable future for the coffee crop and the millions of people dependent on coffee-growing for their livelihoods, it is essential that global collaboration is prioritized in conservation, research and access to improved varieties by farmers. By understanding the threats and vulnerabilities globally and nationally, we will be able to prioritize the agenda for USDA's coffee germplasm collections and research activities. Developed by the CCCGC, this coffee crop vulnerability statement provides background about the crop, threats to genetic resources, current status of genetic resources and capacities, and future needs.

1. Introduction to the Crop

- **Botanical features and ecogeographical distribution**

  A tropical woody genus belonging to the Rubiaceae family, *Coffea* consists of at least 124 species endemically distributed in Africa, Madagascar, the Comoros Islands, the Mascarene Islands (La Réunion and Mauritius), tropical Asia, and Australia (Davis et al. 2006, 2011). One of the first botanical descriptions of the coffee tree was published by de Jussieu (1715) after examining a plant originally growing at the Physic Garden in Amsterdam and given to the French King. Subsequently, Linnaeus classified it under the genus *Coffea* (Linnaeus 1737), and as *Coffea arabica* in 1753 (Linnaeus 1753). Since then, many other *Coffea* species have been described through extensive taxonomic work (Charrier and Berthaud 1985; Davis et al. 2006; Wintgens 2009). Originally confined to the African continent and Indian Ocean islands, the geographic distribution expanded to Asia and Australia when the genus *Psilanthus* was subsumed into *Coffea* (Davis et al. 2011). The Royal Botanic Gardens Kew's World Checklist of Selected Plant Families lists 125 species of *Coffea* (http://wcsp.science.kew.org/qsearch.do), which were listed in the Global Conservation Strategy for Coffee Genetic Resources (Bramel et al. 2017). Following consultation with Aaron P. Davis (Royal Botanic Gardens, Kew), it was clarified that *C. vavateninensis* will become a synonym of *C. coursiana*. Taxonomic details and geographic range for all species can be found in Davis et al. (2006, 2011).

  Two species are economically important in the production of the coffee beverage: *C. arabica* L. (Arabica coffee) and *C. canephora* Pierre ex A.Froehner (robusta coffee). The primary center of origin of *C. arabica* is the highlands of southwestern Ethiopia and the Boma plateau of South Sudan, with wild populations also reported in Mount Marsabit in Kenya (Thomas 1942; Meyer 1965). *Coffea canephora* has a much wider distribution, spreading from West to East Africa in Ghana, Guinea, Guinea Bissau, Cote d'Ivoire, Liberia, Nigeria, Cameroon, Congo, Central African Republic, Democratic Republic of Congo, Gabon, Sudan, South Sudan, Tanzania, and Uganda and to the south to Angola (Davis et al. 2006). Table 1 provides the geographical distribution of all 124 *Coffea* species and the International Union for Conservation of Nature (IUCN) extinction risk category based on IUCN Red List of Threatened Plant Species Criteria (Davis et al. 2019; IUCN 2020).

- **Genetic base of coffee cultivation**

  All species of *Coffea* are diploid with the exception of *C. arabica*, which is a tetraploid. More specifically, *C. arabica* is an allotetraploid (2n=4x=44) that originated from two different diploid (2n=2x=22) wild ancestors, *C. canephora* and *C. eugenioides* S.Moore or ecotypes related to these two species (Lashermes et al. 1999). Arabica coffee is characterized by very low genetic diversity, which is attributed to how it originated, its reproductive biology and evolution, and due to the narrow genepool from which it was disseminated around the world (Lashermes et al. 1999; Anthony et al. 2002; Vega et al. 2008). It is self-compatible and mostly reproduces by self-fertilization. Meyer (1965) reported self-fertilization occurring in 83-95% of the population of *C. arabica* grown in Brazil though this is reduced to 40-60% in the wild plants grown at the Jimma Agricultural Research Center in Ethiopia, alluding to the heterozygous nature of the plants expected in its center of origin. Fazuoli et al. (2000) also report high self-fertility occurring in about 90% of the *C. arabica* in Brazil.

From its early cultivated phase in Yemen in the 14th century (Meyer 1965), two significant dispersion events are documented, one leading to the 'Typica' line and the second leading to the 'Bourbon' line of coffee, which are the two main parental lines of coffee cultivated around the world. This has led to very low genetic diversity of coffee in cultivation. The timelines of the dispersion of the two lines of coffee are presented in Table 2 (Anthony et al. 2002; Vega 2008; Scalabrin et al. 2020; WCR 2020).

Using a genome wide single nucleotide polymorphism (SNP) assay, Scalabrin et al. (2020) analyzed the genetic diversity in *C. arabica* and its relationship with historical records and geographic distribution using 736 accessions. This study concluded that a single hybridization event led to the origin of the tetraploid *C. arabica* about 10,000 or 20,000 years ago based on the severity of the bottleneck effect and the unsubstantiated carry-over of ancestral diversity by the most likely parental *Coffea* species into *C. arabica* population. The available data and computer simulations supported the recent origin of *C. arabica* accessions from a single individual after the polyploidization event. They also conclude that the present-day variation in *C. arabica* arose after the polyploidization event because the distribution of private alleles among *C. arabica, C. canephora* and *C. eugenioides* showed that the majority of the SNPs in *C. arabica* was not shared with either of the parental species. This study also revealed the presence of genetic differentiation in wild *C. arabica* in the southwestern most range of distribution in the rainforests of Ethiopia and that the cultivated varieties used worldwide were genetically similar to the germplasm used in Eastern Ethiopian and Yemeni plantations from which the Typica and Bourbon lineages arose. This concurs with the historical accounts of the global spread of cultivated coffee out of Yemen.

Germplasm conserved in *ex situ* collections throughout the world have come from collecting expeditions in the 1960s, 1970s and 1980s conducted by the Food the Agriculture Organization (FAO), International Plant Genetic Resources Institute (IPGRI, now known as Bioversity International) and various French organizations such as Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM, now known as Institute de Recherche pour le Développement – IRD), Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), and Museum of Natural History, Paris (Bramel et al. 2017). During the development of the global conservation strategy for coffee genetic resources, Bramel et al. (2017) distributed a survey to 32 coffee genebanks, of which 16 responded. One of the main conclusions from the survey was that while the main objective of most of the collections is the conservation of genetic resources, these collections also serve as a tool for breeding programs for a majority of the institutions for development of improved varieties for distribution to farmers in their countries (Krishnan et al. 2018). An inventory of collections, including past inventory and holdings from the 2016 Global Crop Diversity Trust–World Coffee Research survey (https://worldcoffeeresearch.org/media/documents/2016_Annual_Report.pdf), held at various genebanks around the world is provided in Appendix 1.

- **Primary products and their added value**
  Coffee is an important globally traded agricultural commodity that serves as a major source of foreign earnings for many coffee-producing countries. Over 2.25 billion cups of coffee are consumed daily with over 400 million of those consumed in the United States alone (National Coffee Association 2020). Global 2020/2021 production for Arabica has been forecasted at 101.8 million bags (each bag weighing 60 kg) and at 74.29 million bags for robusta (USDA-FAS 2020a). Approximately 23% of the green coffee bean production is imported to the U.S., therefore making the U.S. the top single-country coffee importer (the European Union imports ca. 43%; USDA-FAS 2020a).

- **Domestic and international crop production**
  Coffee production begins at the farms where the coffee berry is harvested and processed to produce the raw product which is then shipped worldwide as green coffee beans. Its primary destination is coffee roasters who then convert the green coffee beans into a consumable roasted final product which represents the basis between the wholesale product and the value-added product. The larger producing countries are Brazil, Vietnam, Colombia and Indonesia (USDA-FAS 2020a). Those countries produce 68% of the world's coffee annually (USDA-FAS 2020a). The US is not a significant coffee producer, with production only in Hawai'i, Puerto Rico and California. The majority of US grown coffee is Arabica.

- **Economic assessment of coffee to US economy**
  Coffee is a significant contributor to the US economy. Roughly half of the US population (i.e., ca. 164 million people) drink some form of coffee drink. In 2015, the U.S. coffee industry estimated coffee's total economic output in the United States at ca. $225.2 billion, which amounts to 1.6% of total US gross domestic product. Consumers spent $75 billion on coffee and coffee products and contributed $28 billion in federal, state and local tax revenue (National Coffee Association 2015). The coffee industry depends on importers, shipping and transport companies, roasters and packagers, the dairy, sweeteners, and flavorings industry, makers of disposable products, coffee brewing equipment sold to households and businesses, and services such as accounting and marketing, among others. From coffee roasting companies, warehouses storing coffee at US ports, and coffee shops throughout the country, coffee generates nearly 1.7 million jobs. The industry imported 3.2 billion pounds of coffee in 2015, which was estimated as $5.2 billion in value based on 2015 prices (National Coffee Association 2015).

2. **Urgency and extent of crop vulnerabilities and threats to genetic erosion**
   - **Genetic uniformity in the "standing crops" and varietal life spans**
     Coffea arabica cultivated around the world fall into four main types (WCR 2019):
     1. Ethiopian landrace – these are genotypes that originated in the forests of Ethiopia which have been locally domesticated and are generally characterized by high cup quality and lower yields. Since 700 AD, farmers in Ethiopia have been planting and selecting coffee plants from different forests; many of these plants are still found in farmers' fields. Surveys carried out between 1989 and 1994 have identified at least 130 landraces by names designated by the Jimma Agricultural Research Center (Bekele and Hill 2018). Many of the Ethiopian accessions held in *ex situ* germplasm

collections were from collecting expeditions undertaken by the Food and Agriculture Organization (FAO) and L'Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM; presently known as Institute de Recherche pour le Développement – IRD) in the 1960s (Bramel et al. 2017; Krishnan et al. 2018).

2. Typica and Bourbon group – The dissemination of these two lines of coffee is summarized in Table 2. Cultivars developed from these two lineages account for a majority of the plants cultivated in Latin America, which has led to severe genetic bottleneck in *C. arabica*. These varieties are associated with high cup quality but are susceptible to major coffee plant diseases. Approximately 97.5% of the varieties cultivated in Brazil, the world's largest coffee, are derived from Typica and Bourbon.
3. Introgressed – Interspecific hybridization in coffee, mostly with *C. canephora* and to a lesser extent with *C. liberica*, has led to introgressed varieties (i.e., the cultivar expresses characteristics of a different species). Spontaneous interspecific hybrids that occur occasionally have also been widely used for improving disease and pest resistance in Arabica coffee (Pearl et al. 2004). An example is the Hybrid of Timor, a natural cross between *C. arabica* and *C. canephora*, discovered in the island of Timor in the 1920s, which has been used intensively in coffee breeding programs for resistance to coffee leaf rust (*Hemileia vastatrix*; Lashermes et al. 2000, Pearl et al. 2004). Introgressed lines of *C. liberica* from a natural cross between *C. arabica* and *C. liberica* have been used as a main source of coffee leaf rust resistance in breeding programs in India (Prakash et al. 2002).
4. F1 Hybrid – development of F1 hybrids by crossing genetically distant Arabica genotypes is a new development in coffee breeding that employs utilizing parents with traits for high cup quality, high yield and plant disease resistance. F1 hybrids tend to have significantly higher yields than non-hybrids. With distribution of F1 hybrids to farmers, there is a need to educate the farmers that F1 hybrids need to be clonally propagated instead of the standard practice of propagating coffee by seeds since seeds collected from F1 hybrids will segregate and lead to loss of hybrid characteristics. In a study comparing F1 hybrids with conventional coffee cultivars to assess the genotype by environment interactions on yield and quality, several F1 hybrids such as Centroamericano, Mundo Maya® and Starmaya outperformed conventional cultivars such as Caturra and Marsellesa® (Marie et al. 2020). The variety Starmaya is a F1 hybrid that was produced using a male sterile parent making it amenable for mass propagation by seeds (Georget et al. 2019).

Since development and/or release of new coffee varieties requires engagement of national coffee institutes or relevant national authorities, the number and diversity of varieties available for farmers depends on what is available at the national level. Combined with the financial dimension, as renovation and replanting of coffee farms involves a significant investment, adoption of new varieties by farmers in many coffee producing countries is very limited. These factors help explain the prevalence of varieties derived from Typica or Bourbon as well as descendants from Hybrid of Timor.

- **Threats of genetic erosion *in situ***

  An analysis was conducted by Davis et al. (2019) to identify both *in situ* and *ex situ* conservation status of all 124 species of *Coffea* by applying the IUCN Red List of

Threatened Species Criteria. The study reported that 60% (i.e., 75 species) were assessed as threatened with extinction with 13 species falling under the category of Critically Endangered (CR), 40 species as Endangered (EN) and 22 species as Vulnerable (VU) (Table 1). The study also reported that 28% of the species are not known to occur in any protected areas and 45% are not held in any *ex situ* germplasm collections. Hence, there is an urgency to expand germplasm collections with yet unrepresented species *ex situ* as well as prioritizing conservation of species *in situ*. Madagascar has the highest number of species, all endemic and with a high percentage (72%) listed as threatened (CR, EN and VU).

In Ethiopia, the United Nation's Educational, Scientific and Cultural Organization's (UNESCO) Man and Biosphere (MAB) reserve program has been implemented to create two reserves to conserve *C. arabica*: the Yayu Biosphere Reserve and the Kafa Biosphere Reserve (Bramel et al. 2017). The Oromia Environment, Forest and Climate Change Authority (OEFCCA) and the Oromia Forest and Wildlife Enterprise (OFWE) engaged numerous stakeholders in a consultancy to develop the Yayu Coffee Forest Biosphere Reserve (YCFBR) Management Plan. By partitioning the forests to core (protected area), buffer (managed use area), and transition (highly used by local people) zones, the aim of the MAB project is to promote interdisciplinary research, training and communications in the field of ecosystem conservation and the rational use of natural resources (OEFCCA & OFWE 2018). Challenges remain in managing these biosphere reserves and to address threats towards conservation and various management constraints.

Using a multidisciplinary approach of literature review, herbarium specimens, fieldwork and DNA sequencing, Davis et al. (2020) investigated the identity, presence and potential cultivation of two *Coffea* species, *C. affinis* and *C. stenophylla* in Upper West Africa. Both species were at one time cultivated on a small scale but are no longer in cultivation and are threatened in their natural habitats in Guinea, Sierra Leone and Ivory Coast. Historical reports indicate both species to have superior taste quality and occurring at lower elevations with the potential for climate resilience. Considering the biotic and abiotic threats to *C. arabica* and *C. canephora*, there is an urgent need to diversify the portfolio of coffee genetic resources and conserve them both *in situ* and *ex situ* (Davis et al. 2020). Similar research needs to be undertaken for all threatened species for prioritization of *in situ* and *ex situ* conservation.

- **Current and emerging biotic, abiotic, production, and accessibility threats and needs**
  - **Biotic (plant pathogens, insect pests, nematodes)**

    The most important biotic factors affecting coffee production and yields worldwide are plant pathogens, pests, including insects and nematodes. The most important fungal pathogen is coffee leaf rust (*Hemileia vastatrix*), which infects coffee leaves and causes severe defoliation. Since the first recorded epidemic in Sri Lanka in 1869, coffee leaf rust has spread to almost all coffee growing regions of the world. Hawai'i was free of coffee leaf rust until October 2020, when infections were detected in Maui and in the Big Island (Hawai'i). In Latin America, it was first detected in Brazil in 1970 and quickly spread throughout the entire coffee-growing region, with losses in 2016 estimated at 30-50% (Zambolim 2016). The most recent epidemic occurred in 2008-2011 in Colombia, 2012-2013 in Central America and Mexico, and in 2014-2015 in Ecuador and Peru, resulting in significant economic losses (Avelino et al. 2015; McCook and Vandermeer 2015). The Hybrid of Timor cultivar was originally resistant to coffee leaf rust. Unfortunately, as new rust races evolved, the resistance was lost. By 2005, 45 different pathogenic rust races had been characterized worldwide (Várzea and Marques 2005), with the number of races reaching 49 by 2012 (Gichuru et al. 2012). Due to the evolution of so many races of the same pathogens, many coffee leaf rust resistant cultivars developed in several countries have lost their resistance (Maia et al. 2013; Avelino et al. 2015). Breeding for resistance to this fungal pathogen continues to be a challenge and a priority (Avelino et al. 2015; Zambolin 2016).

Another important fungal pathogen is *Mycena citricolor*, known in Spanish as “ojo de gallo” (rooster’s eye, based on the typical symptoms on the leaf) and as “mancha americana de la hoja” (American leaf spot). The fungus grows optimally under high humidity conditions which can be more prevalent in coffee under shade (Staver et al. 2001). *Mycena citricolor* causes cyclic epidemics in coffee-producing countries in the Americas, resulting in premature defoliation and fruit drop (Granados-Montero et al. 2020).

Coffee berry disease is a fungal pathogen caused by *Colletotrichum kahawae* (Waller et al. 1993). The disease, which is restricted to Africa, infects green Arabica berries and causes fruit mummification and fruit drop, reducing yields by up to 80% (Silva et al. 2012). Three genes in Timor Hybrid, K7, Rume Sudan, and Catimor confer resistance to Arabica (Agwanda et al. 1997; Gimase et al. 2020).

The coffee berry borer (*Hypothenemus hampei*; Coleoptera) far surpasses all other coffee insect pests in terms of economic importance. For example, the insect is estimated to cause losses of US $215–358 million per year in Brazil (Oliveira et al. 2013) and considering that it occurs in most coffee-producing countries, yearly losses worldwide should easily surpass US $500 million. The main reason why the insect is so devastating is because it is very difficult to control due to its life cycle occurring inside the coffee berry, which makes traditional pest management options mostly ineffective. Climate change has resulted in the insect being able to proliferate in areas that were once too cool to thrive, e.g., some areas of Colombia, Ethiopia, Indonesia, Kenya, Tanzania, and Uganda (Jaramillo et al. 2009; Magina et al. 2010). Climate change models predict significant increases in the number of coffee berry borer generations in East Africa (Jaramillo et al. 2011) and areas infested by the insect are expected to greatly increase for both Arabica and robusta (Magrach and Ghazoul 2015).

Other important coffee insect pests are the coffee leaf miner (*Leucoptera coffeella*; Lepidoptera), an important pest in Brazil; the white coffee borer (*Monochamus leoconotus*; Coleoptera), a pest in various African countries and the white stem borer (*Xylotrechus quadripes*; Coleoptera), a severe pest of Arabica coffee reported in

    China, India, Sri Lanka, Nepal, Vietnam, and Thailand. The root-knot nematode (*Meloidogyne* spp.) has a worldwide distribution with over 15 species documented in different regions (Noir et al. 2003). Climate change projections indicate a higher number of coffee leaf miner and root knot nematode generations in Brazil (Ghini et al. 2008), with higher temperatures shortening the incubation period of coffee leaf rust, thereby speeding up the appearance of symptoms (Ghini et al. 2011).

    Root-knot nematodes adversely affect Arabica production in many coffee growing regions (Campos and Villain 2005). *Meloidogyne konaensis*, the Kona coffee root-knot nematode, causes severe damage to the root systems of *C. arabica* cv. Typica 'Guatemala' grown in Kona (Eisenback et al. 1994). Infection by *M. konaensis* can cause wilting and yellowing of the leaves followed by defoliation and in severely infected areas, death of the tree (Serracin et al. 1999). Developing host plant resistance is an environmentally compatible way of reducing the damage caused by these pests (Barker et al. 1994). Currently, there are no commercial *C. arabica* cultivars identified that provide resistance to nematodes (Anthony et al. 2005). Using species with resistance or tolerance to root-knot nematodes as rootstocks has shown to be an economically viable solution for coffee growers (Bertrand et al. 2001). Other coffee species exist which are highly resistant to insect pests and plant pathogens but have undesirable cupping qualities (Santos-Briones and Hernández-Sotomayor, 2006).

  - **Abiotic (environmental extremes, climate change)**
    The most significant abiotic factor affecting coffee production is climate change. Increased temperatures and decreased rainfall are projected to severely reduce the current areas that are suitable for coffee production in Central America and Mexico (Läderach et al. 2010a), Kenya (Läderach et al. 2010b), Ethiopia (Davis et al. 2012), Puerto Rico (Fain et al. 2018), as well as other countries (Bunn et al. 2015; Ovalle-Rivera et al. 2015; Ranjitkar et al. 2016). Extremes in interannual variation of precipitation and temperature, including change in timing of precipitation, are the most significant abiotic constraints to stability in agricultural production (Baethigan, 2010). As the average lifespan of a coffee plantation is ~30 years (Wintgens, 2009), trees must remain productive in a wider range of temperatures and precipitation levels than has been the case historically. This current production reality requires development and adoption of methods to accelerate coffee breeding to increase the relevance of new varieties to more highly variable production environments. In addition, for California coffee production, mechanisms for extreme heat protection and frost tolerance are critical environmental variables to consider in management and breeding programs.

- **Production/demand (inability to meet market and population growth demands)**
  - **Coffee Valuation**
    Wholesale green coffee is tendered in two categories: the commodity market (referred to as the C market) and the specialty market. The C market is the lower quality bulk that generally is used in any mass-produced type of coffee, which includes canned and soluble products and hundreds of coffee-related items. Low grade Arabica and

robusta coffee make up these products. The specialty market, which began getting a foothold in the market in the late 1980's, is mostly the Arabica species where cup quality dominates the value and the products' ability to sustain itself in this much higher priced sector. Origin, farming practices, environment, sustainability, and coffee genetic variety are major factors in the story to achieve success as a specialty grade coffee.

C-grade coffees in 2020 ranged from a high of 138 cts./lb. to a low of 90 cts./lb (Markets Insider 2020). These are traded daily in the Intercontinental Exchange as futures and options and therefore priced objectively. The specialty grade coffees are much more subjectively traded and through a series of steps that include Q-grading (a system of trained individuals who rate a coffee's many qualities) which must achieve a minimum score of 80 points out of 100, origin, certifications, and farming techniques (i.e., organic or fair trade). Specialty pricing is a premium added to the C price, and some micro-lots have been sold at auction, exceeding 10,000 cts./lb.

  - **Other Coffee By-Products and Added Value Products**
    As stated earlier, green coffee is the actual agricultural product. Any process, by-product, roasted product, extract, solid and liquid forms, etc. make up the value-added coffee industry. The transformation of green coffee to a roasted form is considered the value-added coffee business. The coffee roaster enjoys the highest rate of return in the coffee sales cycle, upwards of 140% markup after purchasing the green coffee at wholesale (Bruce-Lockhart and Terazono 2019).

    Focusing only on the farm commodity itself, besides the roasted retail business of coffee which drives the industry, many other new beneficial industries are forming. The coffee industry produces enormous amounts of coffee by-products which are thriving nutrient sources. Coffee oils, pulps, skins, ground unroasted green bean, tinctures and juices have high significance to the pharmaceutical, cosmetic and food industries. Similarly ground roasted coffee waste contains 15 to 20% decarboxylated oil content that is very suitable to biodiesel production. After the oil is extracted, activated carbon from the remaining waste is useful in creating filters to remove pollutants from the atmosphere and water sources (Murthy and Naidu 2012).

- **Accessibility (inability to gain access to needed plant genetic resources because of phytosanitary/quarantine issues, access and benefit sharing provisions, inadequate budgets, management capacities or legal and bureaucratic restrictions)**
  Breeding of coffee germplasm has successfully incorporated important high yielding, insect pest and plant pathogen resistance traits into commercial coffee cultivars, such as Mundo Novo, Caturra and Catuai from Brazil; Kents and S.795 from India; Blue Mountain from Jamaica; and Castillo from Colombia. Although these cultivars were available in the past, export restrictions by the host countries limit sharing of these important genetic resources. The Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) in Costa Rica is the only coffee genebank that provides public domain coffee germplasm. Coffee is not included in Annex 1 list of crops covered by the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). Coffee accessions in the CATIE collections are distributed under condition listed in

Article 15 of the ITPGRFA. Unless a provider of coffee germplasm chooses to make the material available under the terms of the ITPGRFA's Standard Material Transfer Agreement, coffee germplasm exchanges are covered under the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization under the Convention on Biological Diversity. The scope of this protocol extends beyond genetic resources to include traditional knowledge associated with genetic resources.

- **Vulnerabilities of coffee R & D capacity landscape in relation to production trends** Coffee is exported from over 40 countries globally and in 2018, over 170 million bags of coffee were produced (ICO 2020). Significant global exporters of coffee emerge from all four World Bank income classification levels, with significant global exports from Ethiopia and Uganda (low income countries), while most major coffee exporting countries are lower-middle income countries such as Indonesia, Kenya, Honduras, and Papua New Guinea, all with appreciable global exports, and Vietnam as a global leader in robusta exports. Colombia and Brazil are the primary global exporters of Arabica coffee and are among upper-middle income countries, while there is limited production, such as in the U.S., from high income countries.

  National coffee research capacity and levels of investment are highly variable and are not directly correlated with World Bank income classifications. National coffee research institutions vary by funding model and organizational governance structure. In a number of Central and South American countries, coffee agricultural research and development is supported through revenues collected on marketed coffee and implemented by farmer-governed institutions such as the Instituto Hondureño del Café (IHCAFE) in Honduras and the Centro Nacional de Investigaciones de Café (Cenicafé) in Colombia. In East Africa, national coffee research institutes are generally part of the national agricultural research system and are national public research organizations such as the National Coffee Research Institute (NaCORI) in Uganda and the Rwandan Agriculture Board (RAB) in Rwanda, though may also be funded through a national export tax, as in Uganda (UNCS 2015). For general comparisons, national agricultural research spending as a share of agricultural GDP should be above 1% (IFPRI 2017). Few coffee producing countries exceed 1% in research expenditures for agriculture at large, among them Brazil, Costa Rica, and Mexico (ASTI 2020). One of the key consequences of this relative level of underinvestment in agricultural research is that inquiry in key areas of basic biology, such as host-pathogen interactions, has not been undertaken. Limited knowledge of these foundational topics limits how much applied research can be generated to translate this knowledge to farmer-relevant innovations. For example, understanding the mechanisms of coffee leaf rust infection or the dynamics of rust spore levels in the production environment are critical for development of new varieties with relevant mechanisms for leaf rust resistance or field management systems that reduce spore counts.

  Metrics for assessing national research capacity include numbers of full-time equivalents (FTEs), numbers of PhDs, and numbers of coffee-specific researchers; all these are generally low in most countries in East Africa and parts of Central America, relative to the economic importance of coffee (data are not yet available for key exporting countries in Asia/Pacific) (ASTI 2013). Recent Food for Progress investments by USDA/FAS include capacity assessments for coffee research in Peru, Nicaragua, Guatemala, El Salvador, Honduras, Philippines and Ethiopia (USDA-FAS 2020b).

3. Priorities for establishing coffee genetic resources in the U.S. National Plant Germplasm System (NPGS) for reducing genetic vulnerabilities

- **Germplasm collections and *ex situ* reserves**

  Conservation of coffee in *ex situ* collections occurs in various areas of the world and the worldwide survey of coffee genetic resources provides details on germplasm collections maintaining over 19,000 accessions including *C. arabica, C. canephora, C. liberica, C. eugenioides,* etc. (Bramel et al. 2017).

  The Subtropical Horticulture Research Station (USDA-ARS), in Miami, Florida, was the largest coffee germplasm collection site for the United States. The collection consisted of approximately 300 accessions (Krishnan 2013); however, a lack of funding combined with cool winter temperatures resulted in a significant loss of accessions. The collection was destroyed by Hurricane Andrew in 1992.

  In Hawai'i, the coffee industry started in the mid-1800s in the Kona region on the island of Hawai'i. Several coffee varieties were introduced to Kona, including *C. arabica, C. canephora, C. liberica* and *C. congensis* (Bittenbender and Smith 2008). A small coffee collection was established at the University of Hawai'i Kainaliu Station in Kona. Many of these varieties were lost due the root-knot nematode.

  The Hawai'i Agriculture Research Center (HARC) in the island of Oahu, started coffee research in 1980s. In 1997, HARC started a breeding program at the Kunia and Maunawili stations on Oahu. HARC maintained about 1000 accessions, including F1-F4 breeding populations of Arabica coffee.

  The HARC collection includes:
  1. Arabica varieties which coffee growers cultivate in their farms (Nagai et al. 2001).
  2. Arabica accessions and varieties imported from Brazil and Costa Rica, including semi-wild Ethiopian Arabica accessions resistant to nematodes (Cabos et al. 2010; Aoki et al. 2012) and Catimors and Sachimors resistant to coffee leaf rust (Nagai et al. 2006).
  3. Breeding populations for developing high cupping quality and coffee leaf rust resistance (Pearl et al. 2004).

  In 2019, the USDA-ARS Daniel K. Inouye U.S. Pacific Basin Agricultural Research Center (PBARC) and HARC started to transfer the coffee collection to Hilo.

- **Genetic coverage and gaps**

  The genetic bases for the currently existing collection in Hawai'i has been developed mostly for commercial varieties of *C. arabica*. The majority of the germplasm is *C. arabica* and its genetic diversity is narrower than that of many other coffee producing regions (Steiger et al. 2002). The germplasm collection needs to be expanded with major accessions/ genotypes to identify useful genes for breeding phenotypically or at molecular level.

During the past few decades, accessions of wild and semi-wild Ethiopian Arabica have been used for breeding for various traits. In Hawai'i, there are ten accessions of Ethiopian Arabica which are resistant to nematodes (Aoki et al. 2012) as well as the Ethiopian Geisha variety in coffee growers' fields (Hawaii Coffee Association, personal communication). It is imperative to add selected wild and semi-wild Ethiopian Arabica accessions to be used for breeding and other research.

Only two accessions of diploid species, *C. canephora* and *C. liberica*, are included in the collection. The collection is missing diploid species, which could possibly be a source of favorable abiotic and biotic traits. Recent molecular studies showed the importance of diploid species such as *C. canephora* to identify genes for drought tolerance (Santos et al. 2015; Torres et al. 2019). *C. eugenioides*, a progenitor of *C. arabica* (Lashermes et al. 1999), should be included in the collection.

- **Phytosanitary/quarantine procedures**
  Importation of coffee germplasm is regulated by national and local phytosanitary regulations based upon the risks to the local coffee production. In some cases, importation is restricted, or extended quarantine measures are imposed to reduce risk of introducing insect pests and/or plant pathogens. In the United States, international importation of live coffee plants is prohibited (CFR 319.73-2, 2020) into Hawai'i and Puerto Rico, and coffee plants must be imported under a Controlled Import Permit issued by USDA's Animal and Plant Health Inspection Service (APHIS). Importation of coffee to Hawai'i is prohibited except by permit and grown under approved quarantine facility for a minimum of one year (Hawai'i Department of Agriculture HDOA §4-70-17, 2018). These prolonged quarantine requirements limit the importation of new germplasm which prevents the industry from incorporating new disease resistant material into commercial production leaving the U.S. coffee industry vulnerable. In Puerto Rico, introduction of live plant materials requires a phytosanitary certificate from APHIS and a Special Permit from the state Department of Agriculture. Introduction of treated seed and tissue cultured plantlets may be approved faster. A protocol to safely import coffee germplasm in a timely manner needs to be developed.

- **Associated information**
  - **Genotypic characterization data**
    Accurate genotype information is essential to determine the identification of coffee accessions and assess the genetic gaps and redundancies of the collection. Different molecular markers such as microsatellite (Silvestrini et al. 2007; Labouisse et al. 2020; Pruvot-Woehl et al. 2020), amplified fragment length polymorphism (AFLP) (Steiger et al. 2002), restriction fragment length polymorphism (RFLP), random amplified polymorphic DNA (RAPD) (Orozco-Castillo et al. 1994), and sequence-related amplified polymorphism (SRAP) (Jingade et al. 2019; Huded et al. 2020) markers have been developed to determine the identity and genetic diversity of coffee collections. These markers have resolved many questions on coffee identity

    and diversity; however, an ideal marker system would provide standardized data using different instrumentation. Single nucleotide polymorphisms (SNP) does not require DNA separation by size and can be automated in high-throughput assays. SNP markers have been developed for *C. arabica* and *C. canephora* (Zhou et al. 2016) but more SNP marker development is needed to distinguish cultivars within *C. arabica* using larger germplasm collections. Currently, USDA/ARS and WCR are collaborating to generate a SNP panel including major varieties produced in thirteen countries (and counting) in Central America, Peru, Indonesia, and East and Southern Africa to allow for low cost, low density differentiation of both robusta and Arabica varieties.

    Commercial varieties grown in Hawai'i including Kona typica from multiple farms were genotyped using AFLP (Steiger et al. 2002; Pearl et al. 2004). Accessions and varieties which will be included in the germplasm repository at PBARC will be genotyped by the USDA-ARS Beltsville group using SNPs (Dapeng Zhang, https://www.ars.usda.gov/research/project/?accnNo=436780).

  - **Phenotypic evaluation data**
    Descriptors are essential information for uniform characterization of germplasm accessions. Common descriptors assist repositories in keeping common data on all accessions and allow for comparison of phenotypic traits of the same genotype grown in different locations. The International Plant Genetic Resources Institute (IPGRI; currently known as Bioversity International) publishes lists of descriptors for many crops, including coffee (IPGRI 1996). The published coffee descriptors will be used for all future phenotypic evaluations.

    In Hawai'i, various field trials have been conducted to evaluate yield and morphological characters of Arabica cultivars (Cavaletto et al. 1991; Nagai et al. 2004). As a part of coffee breeding program and genomics and marker development studies, fruit and bean characteristic data including fruit and bean size were also collected.

    Beverage quality is the most important trait for the specialty coffee market. The coffee beverage quality and various micro-climates of Hawai'i have been studied since the 1990s (https://www.coffeeinstitute.org/the-cqi-timeline/). Annual cupping contests by the Hawaii Coffee Association (2009-2019) contributed awareness to Hawai'i coffee growers and processors about beverage quality using the Q-grading system. Metabolomics and chemical component analysis of major commercial varieties have also been studied (Setoyama et al. 2013).

- **Curatorial, managerial and research capacities and tools**
  The PBARC National Clonal Germplasm Repository (NCGR) in Hilo is located on the Island of Hawai'i at the University of Hawai'i, Waiakea Experiment Station (19°38.68 N; 155°04.89 W; 91.2 meters above sea level). The mean maximum and minimum temperatures are 28°C and 16°C, respectively. Annual rainfall averages 4445 mm and is most abundant between October and February. The soil consists of an extremely stony

Papai muck with organic soils formed over mostly fragmental a’a lava. The repository was started in 1987 and the current collection consists of under 1000 accessions. There are currently 38 acres at Waiakea and small plots of ½ to 1 acre at the Volcano and Lalamilo stations. In addition, a three-acre plot at Paauilo is currently leased from a farmer’s cooperative. Paauilo is different from all other sites, with dry, hot days and cool nights. The Hilo repository has a field laboratory at Waiakea with tissue culture capacity, a head house, three greenhouses, a plant introduction quarantine house, two screenhouses (portable), and a portable tractor storage shelter. The PBARC facility includes special plant quarantine house for plant disease research; growth chambers to recreate favorable conditions for disease expression, tissue culture, molecular marker research, advanced genetics, and biochemical analyses. The genebank staff consists of the curator, five field technicians, one tissue culture technician and one database manager. In addition to the curator, three scientists (Geneticist, Horticulturist, Plant Pathologist) and technicians are stationed at the main PBARC facility.

Acquisition

The U. S. National Coffee Germplasm Collection will be housed at NCGR-Hilo. Some coffee species and varieties are available from other collections in Hawai’i, i.e., HARC, the University of Hawai’i, and the Hawai’i Coffee Growers Association. Agreements must be negotiated with those organizations and with international organizations that have coffee germplasm collections (e.g., CATIE). New accessions must be imported into Hawai’i in compliance with USDA-APHIS phytosanitary restrictions and quarantine procedures. World Coffee Research (WCR) generated molecular analysis that informed the selection of a core collection from the 900+ trees in CATIE’s collection. This core collection has been backed up in three locations: 1) Flor Amarilla (WCR’s farm in Santa Ana, El Salvador; 2) Hacienda Alsacia, the Starbucks farm in Costa Rica; and 3) at the Rwandan Agricultural Board in Rwanda. Seeds from the core collection will be sent to Honduras from the 2020-21 harvest to plant at IHCAFE for their breeding program. All the genetic material is moved with the Standard Material Transfer Agreement of the International Treaty on Plant Genetic Resources for Food and Agriculture. Based on availability of funds, USDA acquisition could first focus on this core collection as well.

Maintenance, Regeneration, and Distribution

The NCGR-Hilo coffee germplasm repository maintains and operates a living clonal collection in 38 acres of field plantings, greenhouses and a tissue culture laboratory. In addition to the coffee plants maintained in the field, duplicate “safety back-up” samples must be maintained at the NCGR-Hilo in greenhouses or tissue culture. Additional safety backup plantings will be established at the USDA-ARS Tropical Agricultural Research Station in Mayagüez, Puerto Rico. Long term, cold storage-cryopreservation for coffee seeds and tissue cultures of advanced coffee research lines, hybrids, and cultivars would take place at the USDA-ARS National Laboratory for Genetic Resources Preservation (NLGRP) in Fort Collins, CO.

Documentation and Data Management

Information associated with plant genetic resources, such as the descriptive and analytical data discussed below, are increasingly important to researchers, breeders and growers.

The NCGR-Hilo genebank has one computer assistant dedicated to database management in GRIN Global.

Genetic Characterization

Genetic characterization for coffee genetic resources from sources in Hawai'i and elsewhere are required to identify the key samples to incorporate into the U. S. National Coffee Germplasm Collection at NCGR-Hilo. The characterization data also are key for maintaining the genetic integrity of the samples and guiding current and future domestic and international coffee research and breeding programs. NCGR-Hilo will work in collaboration with the USDA-ARS Sustainable Perennials Crops Laboratory (SPCL; Beltsville, MD) to molecularly characterize the coffee collection and provide breeding tools for crop improvement.

Evaluation

Few of the available coffee genetic resources have been evaluated for resistance to plant diseases (e.g., coffee leaf rust, American leaf spot), insect pests (e.g., coffee berry borer), parasitic plant nematodes (e.g., coffee-root nematode), tolerance to extreme weather and changing climates, yield, and cup quality (Bramel et al. 2017). Evaluation data for coffee genetic resources for increasing and protecting coffee yield and quality in Hawai'i and elsewhere will be conducted in conjunction with HARC, the University of Hawai'i, and coffee growers in Hawai'i and Puerto Rico.

4. Prospects and future developments

Although preservation of wild coffee species is necessary for continual crop improvement, 60% of all coffee species are threatened with extinction, 45% are not held in any germplasm collection, and 28% are not known to occur in any protected area (Davis et al. 2019). Coffee germplasm in national collections are facing decreasing funding and often their accession are not shared with others or backed up at other locations (Bramel et al. 2017; Krishnan et al. 2018).

Access to wild relatives of coffee and a robust molecular characterization are essential for conservation of genetic diversity and successful breeding of cultivars. The adverse effects of climate change and increased insect pests and plant pathogens pressure will decrease yields and reduce the areas currently suitable for coffee production. Development of long-term storage strategies for coffee germplasm will decrease costs for large *in situ* collections, enabling repositories to focus on the most promising accessions while still preserving access to all material.

Some of the future conservation and research activities to be undertaken include:

- Development of a means to communicate with coffee producers in Hawai'i, Puerto Rico and California to make sure growers and scientists share common goals
- Expansion of collections to include additional diploid species, CATIE's collection, and other significant germplasm
- Initiation of a surveillance and management program for coffee leaf rust in Hawai'i
- Development of education programs for producers about varieties

- Support of basic biology studies related to host-pathogen interactions, with particular emphasis on coffee leaf rust.
- Development of a disaster response plan for each coffee growing region for future climate resilience
- Investment in infrastructure and personnel for cryopreservation for long-term back-up of collections
- Development of standardized molecular techniques for DNA fingerprinting all major germplasm collections globally
- Development of protocols for safe movement of germplasm in a timely manner
- Initiation of breeding programs to shift to genome-wide selection and marker assisted breeding to accelerate development of varieties adapted to climate change with higher cup quality and/or more diverse, differentiated coffee flavor.
- Development of tools to ensure variety identification throughout the supply chain.
- Participation in the USDA sponsored Agricultural Genome to Phenome Initiative (AG2PI).

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Table 1. Total number of species and number of species within each International Union for Conservation of Nature (IUCN) extinction risk category by main area of geographic distribution. IUCN Red List Categories are as follows: CR – Critically Endangered; EN – Endangered; VU – Vulnerable; NT – Near Threatened; LC – Least Concern; DD – Data Deficient.

Distribution Area	**# Species**	**IUCN Red List Category (# Species)**					
		CR	**EN**	**VU**	**NT**	**LC**	**DD**
West Africa	24	4	3	4	2	9	2
East Africa	20	2	9	3	2	3	1
South Africa	4			1			3
Madagascar	60	7	26	10	4	11	2
Indian Ocean Islands	3		1	2			
Asia	12		1	2	1	2	6
Australia and Papua New Guinea	1					1	
Total	**124**	**13**	**40**	**22**	**9**	**26**	**14**

Table 2. Timeline for dispersion of two important *C. arabica* lines that led to the Typica and Bourbon varieties.

Typica	Bourbon
• 1670 – seeds smuggled to India by Baba Budan • 1696-1699 – seeds taken to Java by Dutch East India Company • 1706 – plants were taken from Java to the Amsterdam Botanical Garden • 1713 – from Amsterdam Botanical Garden, a plant taken to France, which was used by Antoine de Jussieu to first describe coffee **Dispersal by the Dutch** • 1718 – plants introduced to the Dutch colony in Suriname in South America from Amsterdam • 1719 – from Surinam plants were introduced to French Guiana • 1727 – introduced to Brazil **Dispersal by the French** • 1720 – one plant was taken to the French colony of Martinique in the Caribbean from France, from where it spread throughout the Caribbean islands • 1725 – introduced to Haiti • 1726 – introduced to Guadeloupe • 1730 – introduced to Jamaica • 1748 – introduced to Cuba • 1755 – introduced to Puerto Rico	• 1715 & 1718 – plants introduced from Mocha in Yemen to Bourbon Island (present day La Réunion) • Mid-19th century – plants were introduced to the Americas and East Africa **Americas** ○ 1860 – Brazil **East Africa** ○ 1859 – Zanzibar ○ 1862 – Tanzania ○ 1893 – Kenya

Appendix 1. Inventory of coffee *ex situ* field collections (number of accessions) as reported in Bettencourt and Konapka (1988), Dulloo et al. (2009), FAO-WIEW database (http://www.fao.org/wiews/en/), Other (Eira et al. 2007; Labouisse et al. 2008; Phiri 2013), and in the Global Crop Diversity Trust-World Coffee Research 2016 study (https://worldcoffeeresearch.org/media/documents/2016_Annual_Report.pdf).
Source: Bramel et al. 2017

Country	Institution	Bettencourt & Konopka 1988	Dulloo et al. 2009	FAO WIEWS (1990-2011)	Other	GCDT-WCR Survey 2016
Australia	Queensland Government Department of Agriculture					67
Benin	Unité de Recherche Café et Cacao (URCC)			28		
Brazil	Instituto Agronômico do Paraná (IAPAR)		2,976	3,335		2,015
Brazil	Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG)		1,160		1,326[1]	1,596
Brazil	Instituto Agronómico de Campinas IAC)	305	5,101	4,152		
Brazil	Embrapa Café/ Instituto Capixaba de Pesquisa, Assistencia Technica e Extensao Rural (INCAPER)		375	200	375[1]	
Brazil	Universidade Federal de Viçosa (UFV)				1,036[1]	
Brazil	Fundação Procafé, Empresa Brasileira de Pesquisa Agropecuária (Embrapa)				1,518[1]	
Brazil	Embrapa Rondonia			70	981[1]	
Cameroon	Institut de la Recherche Agronomique pour le Développement (IRAD)	1,750	1,552			
Colombia	Centro Nacional de Investigaciones de Café 'Pedro Uribe Mejia' (Cenicafé)	1,804	1,804	1,119		800
Costa Rica	Centro Agronómico Tropical de Investigación y Enseñanza (CATIE)	1,309	1,992	1,835		1,960
Costa Rica	Instituto del Café (ICAFE)			300		58
Côte d'Ivoire	Centre National de la Recherche Agronomique (CNRA)	6,990	8,003	7,500		6,900
Cuba	Estación Central de Investigaciones de Café y Cacao (ECICC)			1,597		
Democratic Republic of the Congo	Institut National pour l'Étude et la Recherche Agronomique (INERA)	58		58		
Dominican Republic	Centro Norte de Investigaciones Agropecuarias y Forestales (CENIAF)			14		
Ecuador	Departamento Nacional de Recursos Fitogenéticos y Biotecnología (DENAREF)			229		
Ecuador	Estación Experimental Tropical Pichilingue (EETP)			163		
Ethiopia	Ethiopian Biodiversity Institute (EBI)	522		1,273	5,196[2]	4,631
Ethiopia	Jimma Agricultural Research Center (JARC)	1,284	4,652	1,284	4,780[2]	
Ghana	Cocoa Research Institute of Ghana (CRIG)			500		

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[1] Eira et al. (2007)
[2] Labouisse et al (2008)

Country	Institution	Bettencourt & Konopka 1988	Dulloo et al. 2009	FAO WIEWS (1990-2011)	Other	GCDT-WCR Survey 2016
Germany	Greenhouse for Tropical Crops, Institute for Production and Nutrition of World Crops, Kassel University (GHK)			10		
Guinea	Centre de Recherche Agronomique de Seredou (CRAS)			104		
Guyana	Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD)			3,800		
India	Central Coffee Research Institute (CCRI)	611	575	575		353
Indonesia	Indonesian Coffee and Cocoa Research Institute (ICCRI)		1,637			
Kenya	Coffee Research Foundation (CRF)	634	2,507	513		800
Madagascar	Centre National de Recherche Appliquée au Développement (CENRADERU)		171			407
Malaysia	Rice and Industrial Crop Research Centre, Malaysian Agricultural Research and Development Institute (MARDI)			15		
Mexico	Banco Nacional de Germoplasma Vegetal, Departamento de Fitotecnia, Universidad Autónoma de Chapingo (UACH)			55		250
Mexico	Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP)			73		
Nigeria	National Center for Genetic Resources and Biotechnology (NACGRAB)			10		
Papua New Guinea	Coffee Industry Corporation Limited (CIC)					90
Peru	Estación Experimental Agraria Tulumayo (INIA-EEA-TUL)	99		99		169
Portugal	Centro de Investigação das Ferrugens do Cafeeiro (CIFC)	82		71		
Puerto Rico	Estación Experimental Agrícola de Adjuntas, Universidad de Puerto Rico (UPR)			70		
Réunion (France)	Laboratoire des Ressources Génétiques et Amélioration des Plantes Tropicales (ORSTOM)			490		742
Rwanda	Rwanda Agriculture and Animal Resources Development Board (RAB), Rubona Station	139		139	182[3]	
Sri Lanka	Department of Export Agriculture (DEA)			15		
Taiwan	Chiayi Agricultural Experiment Station (TARI)			33		
Tanzania	Tanzania Coffee Research Institute (TaCRI)	94	110			
Thailand	Horticultural Research Institute, Department of Agriculture (HRI-DA)			25		
United Kingdom	Millennium Seed Bank Partnership, Royal Botanic Gardens, Kew (RBG)			10		
USA	Subtropical Horticultural Research Station, US Department of Agriculture, Agricultural Research Service, Miami, FL	304	300			
USA	College of Tropical Agriculture and Human Resources (CTAHR), Kainaliu, Kona, Hawai'i	33				

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[3] Phiri (2013).

Country	Institution	Bettencourt & Konopka 1988	Dulloo et al. 2009	FAO WIEWS (1990-2011)	Other	GCDT-WCR Survey 2016
Uganda	National Coffee Research Institute (NaCORI), Coffee Research Center (COREC) part of National Crop Resources Research Institute (NaCRRI)				120[2]	
Venezuela	Instituto Nacional de Investigaciones Agrícolas (INIA), Monagas			51		
Venezuela	Instituto Nacional de Investigaciones Agrícolas (INIA), Táchira			254		
Vietnam	Ba Vi Coffee Research Center (CRC)			70		
Vietnam	Coffee and Cocoa Research Institute			56		
Vietnam	The Western Highlands Agriculture & Forestry Science Institute (WASI)			86		188
Zimbabwe	Coffee Research Institute			2	13[2]	